A Multi-Material 3D Printing Approach for Conformal Microwave Antennas

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***Abstract*—In this paper a new approach for implementing conformal antennas using direct digital manufacturing is presented. The new approach is based on fused deposition printing of a 150 micron-thick thermoplastic layer on top of Kapton tape forming a smooth, thin and flexible substrate. The antenna metallization is then printed on the smooth face of the flexible substrate using micro-dispensing, and the substrate is subsequently adhered to a 3D form. This approach represents a simple and versatile method for building microwave components as 3D structures. A 6 GHz 3D dipole is presented as an example to validate the fabrication approach. An acrylonitrile butadiene styrene (ABS) substrate (relative permittivity of 2.7 and a loss tangent of 0.008) and Dupont CB028 silver paste are used to fabricate the dipole antenna.**

Keywords—dipole; balun; flexible substrate;3-D.

I. INTRODUCTION

Flexible antennas are gaining in popularity with the growth of wearable electronic devices and the overall utility of conformal integration. Many designs are available in the literature for various antenna types and different applications [1-6]. In [1] and [2] a bow-tie antenna on top of heat stabilized polyethylene naphthalate (PEN) flexible substrate is presented, where the authors conformed the proposed antenna on top of a curved surface and analyzed the effects of curvature on the pattern and resonance frequency. Another fabrication technology is presented in [3], where a UHF antenna and solar cell array are printed on top of a thin Kapton sheet. The antenna is formed by depositing an Al layer using a shadow mask and e-beam evaporation. In [4], a flexible PCB is used for the design of a flexible ultra-wide band antenna for mobile devices applications. An investigation on the radiation pattern of 5.8 GHz flexible patch antenna is presented in [5], where the change in pattern and resonance frequency versus changes in the bending angle are described. A similar investigation of flexible antennas is described in [6], which uses copper-etched antennas on flexible polyimide substrates.

Herein, a new approach for implementing 3D microwave devices using flexible substrates is presented, using a combination of micro-dispensing and fused deposition modeling (FDM) for fabrication. Dupont CB028 silver thick film paste is a popular material used with micro-dispensing for conductor deposition, given its relatively low curing temperature (90 – 150 °C), its viscosity (15,000 to 30,000 cP), and its ability to flex after curing. However, tight dimensional control when micro-dispensing CB028 over conformal structures can be difficult to achieve, especially over objects with sharp angles or inclined planes. The approach used here is to print a thin layer of thermoplastic substrate using fused deposition modeling, deposit the CB028 patterns, and then leverage the flexibility of the CB028 by forming the thin and flexible substrate to the desired 3D surface. As an example of the proposed approach, a 6 GHz 3D half-wave dipole is presented, where the antenna and circuitry are placed along a 3D acrylonitrile butadiene styrene (ABS) structure in a conformal manner. An additional advantage of this approach is that the thin substrates on which the conductors are printed can be more than 3x smoother than when printing directly on 3D structures fabricated using the fused deposition modeling process, thereby increasing the effective RF conductivity of the printed lines.

II. FABRICATION APPROACH

This work uses an nScrypt 3Dn Tabletop printer that combines fused deposition modeling and micro-dispensing on a common gantry capable of 2 micron position accuracy. The advanced capabilities of the FDM printer provide the ability of printing thin thermoplastic layers down to 50 ~ 75 μm, and these layers can act as a base for the conductor deposition as shown in Fig. 1. The flexible ABS substrate (Fig. 2) is printed on top of Kapton tape to provide a smooth face and then this face is turned over to be used for the silver paste deposition. Once the conductor is deposited on the thin layer, the flexible substrate is affixed to a 3D ABS structure produced via FDM in a conformal manner. A diagram that describes the steps involved in the proposed approach is shown in Fig. 3.

There are several important advantages gained by having a smooth surface on which the silver paste is deposited. As shown in [7], a reduction in surface roughness also reduces the attenuation constant of the printed lines. From a fabrication standpoint, the print speed during the micro-dispensing process can be increased and the line width control is enhanced when printing on smoother surfaces. Finally, the smooth surface improves the adhesion of the flexible substrate to the 3D structure and minimizes air gaps which can alter the propagation constant along the transmission lines.

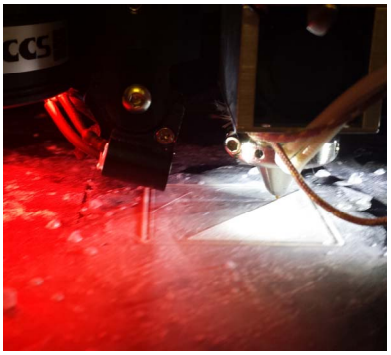

Figure 1: Fused deposition modeling process.

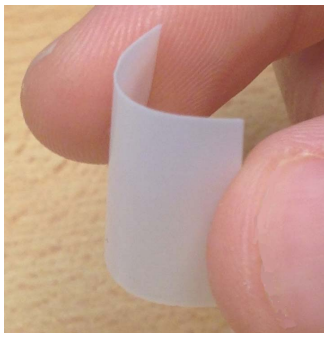

Fig. 2. Flexible ABS substrate (150 microns thick).

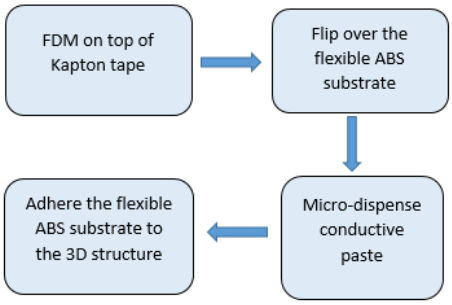
FDM on top of Kapton tape
Flip over the flexible ABS substrate
Micro-dispense conductive paste
Adhere the flexible ABS substrate to the 3D structure

Fig. 3. Steps involved in the fabrication process.

III. Design Example

The described fabrication process is applied to a new volumetric approach to realizing a 3-D half-wave dipole, where the presented design enhances antenna gain and minimizes surface-wave loss. The 3D antenna structure consists of a half-wave dipole located on the top layer of a 3D substrate, ~λ/4 from the bottom ground plane at the design frequency, and the feeding is achieved via an inclined grounded coplanar waveguide (GCPW) balun. A GCPW quarter-wave transformer is incorporated to match the balun to the 50 ohm feed line, as illustrated in Fig. 4. The ground plane is deposited on the bottom of the 3D structure for shielding purposes. Due to the variation of the transmission line characteristic impedance as the distance from the lower ground to the GCPW increases along the inclined plane, the balun presented in [8] has been adopted and modified to optimize the GCPW characteristic impedance along the inclined plane. The antenna design frequency is 6.0 GHz and acrylonitrile butadiene styrene (ABS) substrate material (ε_r ~ 2.7 and tanδ ~ 0.008) is used, with a total size of 21×22×6.25 mm^3. The flexible substrate (150 µm thick) is fabricated by printing two 75 µm layers, and then the conductive layer (including the dipole, balun, matching network and feeding line) are deposited on the smooth face of the flexible substrate as shown in Fig. 5. A profilometer scan for the smooth (bottom (Kapton) side) and rough (top side during FDM print) surfaces of the flexible ABS substrate is shown in Fig. 6. The measured surface roughness (Ra) is 9.14 µm and 2.8 µm for the rough and smooth faces, respectively. The conductivity used to model the CB028 silver paste is 0.6e6 S/m.

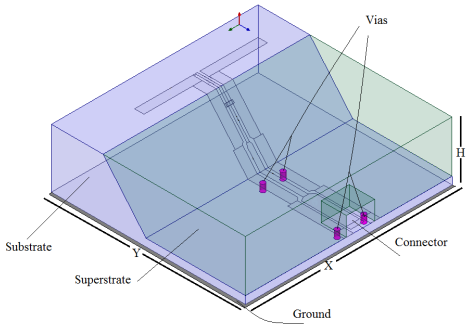

Fig. 4. 3D 6 GHz antenna design.

Experimental results show excellent agreement between the measurement and the simulation, where the simulated and the measured S_{11} are less than -20 dB at the resonance frequency as shown in Fig. 7. The antenna radiation pattern is shown in Fig. 8, where the maximum simulated and measured gains are 3.99 dBi and 3.95 dBi, respectively. The gain is reduced by ~1 dB due to the lower RF conductivity of the CB028 compared to its measured DC value of ~2e6 S/m [9]. The manufactured antenna is shown in Fig. 9.

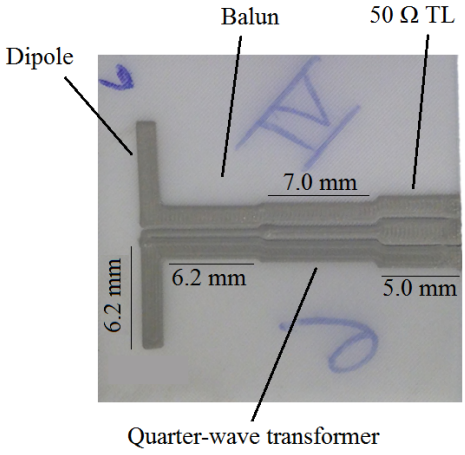

Fig. 5. Dipole and feed network on the flexible ABS substrate.

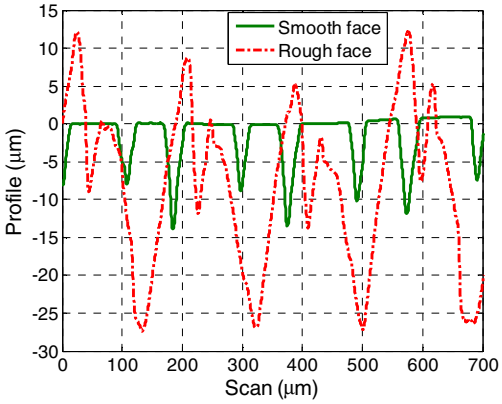

Fig. 6. Profilometer scan.

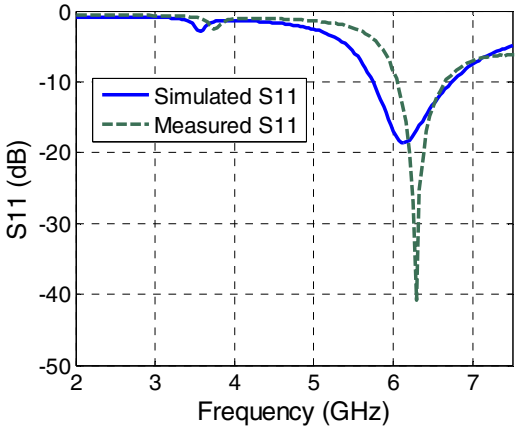

Fig. 7. Measured and simulated S11.

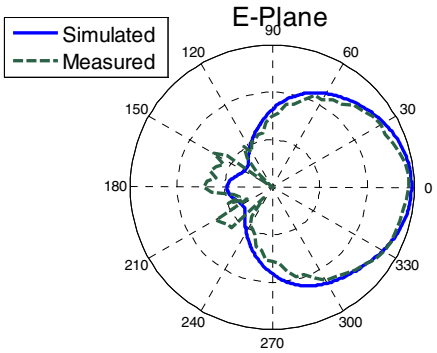

Fig. 8. Measured and simulated normalized radiation pattern (10 dB/division).

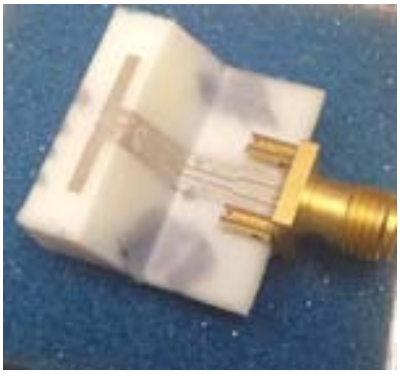
Fig. 9. Manufactured 6.0 GHz antenna with superstrate removed to show the conformal circuity.

IV. Conclusion

In this work, a new approach for implementing flexible antennas using micro-dispensing direct-print additive manufacturing (DPAM) and FDM processes is presented. The approach is useful for accomplishing 3D conformal designs, allows conductors to be printed on relatively smooth surfaces of FDM-printed substrates, and allows for faster conductor printing with excellent dimensional control. This method also eliminates the challenges of silver paste dispensing on structures with sharp edges or inclined planes. The concept was proven with a 6 GHz 3D dipole antenna, and the measurements agree with the simulated performance.

V. References

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